DESIGN Of IMPROVED CHARCOAL PRODUCTION BRICK KILN WITH EMISSION CONTROL TECHNOLOGY AT LOW COST

Environmental Engineering Master's Thesis

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A Thesis Submitted to the school of graduate studies of Addis Ababa Science and Technology University School of Biological and Chemical Engineering

IN

Partial fulfillment of the requirement for the degree of Master of Science in Environmental Conformity with the Requirements for the Degree of Master of Environmental Engineering

Approved by Board of Examiners

Dr. Amare Turuneh	________________	______________
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External Examiner	Signature	Date
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Internal Examiner	Signature	Date

DECLARATION

I hereby, declare that this thesis is my own work and that, to best of my knowledge and belief, it contains no material which has been accepted or submitted for the award of any other degree or diploma.

I also declare that, to the best of my knowledge and belief, this thesis contains no material previously published or written any other person except where due reference is made in the text of the thesis.

Zelalem Getahun

ABSTRACT

Charcoal is the major household fuel in developing countries, while developed world also uses charcoal for industrial energy source. “Charcoal” is produced from wood and other biomass types in a process of carbonization. Carbonization is burning wood or other biomass in the absence of air. Brazil is the leading country by producing charcoal to use as energy source for metallurgical industries and for cooking food. The next country produces large amount of charcoal is Ethiopia which uses for cooking, making Coffee and heating house during cold season.

In this project brick kiln is design with 1.25m^3 volume. 1.1m^3 wood was loaded for one batch. The kiln operates by batch process, which wood was loaded and charcoal discharged at the end of production process. 85kg of charcoal (with 9% moisture content and 1.5% ash content) was produced from 223kg of *Eucalyptus Globulus* wood with 29.5% moisture content.

Wet packed (gravel) scrubber technology was used to treat emission from charcoal producing unit. It was filled with gravel of different aggregate size such as 48-60mm, 27-33mm and 16-20mm from the bottom to the top respectively. This experiment was tested by filling gravel with 40cm depth in the tower for three different arrangement. For the first test, it was configured as follows: 48-60mm gravel by 20cm thickness, 27-33mm gravel by 10cm thickness and 16-20mm gravel by 10cm. for the second test, it was configured as follows: 27-33mm gravel by 20cm thickness and 16-20mm gravel with 20cm thickness. The third was tested using 48-60mm gravel by 40cm thickness. Therefore, this technology control particulate matter trapped on gravel and washed down by showering water. Additionally, hydrocarbons were removed by 97.8%, CO_2 by 98.5% and CO removed by 99%.

Therefore, wet packed (gravel) scrubber was effective and feasible to control gases emitted from charcoal production at low cost.

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First of all, I would like to thank God for his leadership and care in all my ways. Next I want to address my sincere thanks to my advisor Dr. Amare Turuneh, from Addis Ababa Science and Technology University. This research work was formulated with his great support and encouragement. Really, without his kind support it would have been very difficult to finish the study.

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Last but not least, I would like to thank my family for their support. Nobody has been more important to me in the pursuit of this project than them.

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ABBREVIATION

E.Camaldulensis: Eucalyptus Camaldulensis

E.Globulus: Eucalptus Globulus

EPA: Environmental Protection Authority

ESP: Electrostatic Precipitation

ETB: Ethiopian Birr

FAO: Food and Agriculture

GHG: Greenhouse Gas

HC; Hydrocarbon

Hrs: hours

ICPS: Improved Charcoal Production system

IBK: Improved Brick kiln

Kg: kilogram

O and M: Operation and maintenance

PM: particulate Matter

POM: Polycyclic Organic Matter

VOC: Volatile Organic Compound

CHAPTER ONE

1. INTRODUCTION

1.1. Background of Study

Charcoal is universal energy source for human being. The black rock called "Charcoal" is produced from wood and other biomass types in the process of called carbonization. Carbonization is the method of burning wood or other biomass in the absence of air (O_2) to break down into liquids, gases and solid char (charcoal). Charcoal is porous, solid, amorphous products containing 20 to 25 percent volatile matter, 70 to 75 percent fixed carbon (85 to 98 percent total carbon), 5 percent ash and low sulfur. Good charcoal characterized by its heating value which is about 28 kilojoules per kilogram (kJ/kg).[4] Different history tell us the introduction of charcoal lead to the development of energy intensive of industry establishment, such as glass production and metal smelting as no other energy source at the time could produce enough heat. These industries expanded rapidly and were followed by an extensive use of biomass and wildwood clearance. Many areas met a faster growing industry than the availability of the energy resource and this leads to a rapid switching from charcoal to fossil fuel in developed world. But in developing countries charcoal is used as energy source and as income generation still now. [4]

Charcoal is used for cooking and heating rooms in the most of African countries. In most part of this continent, charcoal is one of the preferred fuels due to both its suitability and affordability. Western countries used charcoal for metallurgical and glass processes during ancient time before it's substituted by "coal". Different literatures state that large amount of charcoal is produced in Africa. For instance Ethiopia consumes about 3.2 million tons of charcoal per year. [38] In Ethiopia most of the households use charcoal, even if, they have the access of electricity.

Charcoal is traditionally produced in earth mound, brick and steel drum kiln for batch process to produce 1 to 5 tons per batch. [2] [3] Charcoal production process start by gathering wood and pile to the required size. If the process is traditional, wood stack in hole and covered by soil. If charcoal is produced in kilns, the wood arranged in kiln and the openings are close and carbonization continue. The kiln/mound is fired and the wood heats up and begins to pyrolysis. The kiln is mostly sealed, although a few air pockets are initially left open for steam and smoke to escape. As the gases start to emit from the kiln, the time it changes its color, the charcoal producer may seal some air pockets to control carbonization of wood. The traditional production process may take up to a week. About half of the energy in the wood is typically lost in the process as flue gases and water vapor are evaporated. At the end of the process, the kilns are opened or dug up and the charcoal is removed.

The wood combustion theory state that there are many types of products and byproducts from charcoal production operations: charcoal, gases (carbon monoxide [CO], carbon dioxide [CO_2], methane, and ethane), pyro acids (primarily acetic acid and methanol), tars and heavy oils, and water. With the exception of charcoal, all of these materials are emitted with the kiln exhaust.

The critical factors in the production of charcoal appear to be the operational and supervision skills of the charcoal producer, the moisture content of the utilized wood, and the wood fuel species used. When trees are being cut, their wood contains 50% up to 60% water (on a wet basis). [10]The production technology used is also important. Traditional earth mound charcoal production has subsequent impacts on the environment and labor conditions/producers conditions. The question is that at what extent the wood is to be dried prior to carbonization, and it should be analyzed from two angles: attainable yield and productivity. Theoretical thermodynamically, equilibrium analysis for an ideal process without heat losses shows that the charcoal making process does not require the wood to be dried further than about 50% (w) prior to the carbonization process. One can also make charcoal from wood at higher moisture contents, but then one has to sacrifice part of the material that otherwise could have been turned into charcoal.

Now a day some researchers are trying to produce charcoal in efficient ways. The development of the Adam retort kiln and similar devices such as basic steel retort systems introduced the partial afterburning of pyrolysis gases. In these retort systems the feedstock wood can be mixed with dry biowaste materials like pruning's, rice husks or maize cobs but a lot of valuable start-up wood is still needed. [5, 34] Such medium-scale improved retort technologies, where the pyrolytic gases are recirculated into the combustion chamber and combusted internally [35], produce around 75% lower deleterious gas emissions (mainly CO, CH_4, aerosols) and higher conversion efficiencies of 30–45% than traditional systems. Energy contained in the recirculated carbon- and hydrogen rich syngas is thus used to sustain the pyrolysis process so that less heat from the endothermic pyrolysis reactions is needed to sustain the process. [5, 34] Moreover, the recirculation of pyrolytic gases leads to enhanced secondary char formation which also increases yield. [36, 37]

1.2. Statement of the Problem

Charcoal is one of the main fuels in developing countries especially in Sub-Saharan Africa. Charcoal demand is already fairly large, (e.g. Ethiopia 3.2 million tons per year [38]) and is increasing rapidly. Worldwide consumption is estimated at 40.5 million tons annually, with 19.8 million tones just for Africa.[4]

The production of charcoal lead to high associated with GHG emissions and an unsustainable supply of biomass in which forests are being depleted for the production of charcoal because of use of inefficient technologies to convert wood into charcoal with low yields. Earth mound/hole charcoal production tends to low conversion of wood into charcoal leads to a high level of GHG emissions. Even if, charcoal production is highly emitting CO_2, which needs mitigation method, also kiln design has great role to control specific organic compounds that may be found in charcoal kiln emissions include ethane, methane, ethanol, and polycyclic organic matter. If un-combusted, tars may solidify to form PM emissions, and pyroacids may form aerosol emissions.

Charcoal production emissions control from scattered traditional system is difficult and the yield also very low. For some amount of wood weight, if the yield is very low, the most amounts are exposed to environment for the pollution. Therefore to save the environment, technologies of production and emission control should be developed. For instance one ton of mound charcoal production emits $7*10^5$ m^3 (CO, CO_2, PM and HC) of air pollutant to environment. [5] If this figure is multiplied by Ethiopia's consumption, $2.24*10^{12}$ m^3 of air pollutant is emitting per year solely from charcoal production and $13.86*10^{15}m^3$ of air is emitting to environment per year only in Africa. So installing cyclone and fabric filters technology charcoal production at small scale is difficult or it may be not possible. As result this research/project is required to solve this problem by designing brick kiln with emission control method at low cost. This helps charcoal producer to save labor force by increasing yield, which increase income from the same amount of wood and to protect their health. So that, if the collection of producers use this technology, country, continent and world will enjoy sustainable environment. Charcoal may also be called renewable charcoal, if renewable biomass resources used for charcoal production.

1.3. Research Questions

i. What are the properties of charcoal and yield produced from *eucalyptus globulus* tree?

ii. How is the effectiveness of wet packed (gravel) scrubber to remove emission from charcoal production smoke?

iii. Which gravel configuration gave the best result?

1.4. Objectives of the Study

1.4.1. General objective

To design improved charcoal production brick kiln with emission controlling technology at low cost

1.4.2. Specific objectives

1. To design and characterize charcoal production brick kiln
2. To characterize charcoal which is produced from eucalyptus globulus wood
3. To design emission controlling technology (wet packed scrubber packed from gravels)

CHAPER TWO

2. LITERATURE REVIEW

2.1. Charcoal production and Emission

Charcoal is a black residue consisting of carbon and a remaining ash obtained by removing water and other volatile constituents from wood/combustible materials. Charcoal production involves thermal decomposition of wood, and can be carried out in open pits, kilns or retorts. Charcoal production in open pits and kilns takes place with a more or less controlled air supply and allowing for heat supply by burning part of the wood. In retorts, charcoal is produced in the absence of air, implying that heat supply must come from another source.

By products of charcoal production are: CO, CO_2, methane, particulate matters, heavy oils and water vapors. The distribution of these constituents vary, depending on raw materials and carbonization parameters. Volatile organics matters and CO are naturally combusted to CO_2 and water before leaving the retort. Some of the specific organic pollutants that may be found in kiln emissions include ethane, methane, methanol, and polycyclic organic matter (POM). Un-combusted tars may solidify to form particulate matter (PM) emissions, and pyro-acids which may form aerosol emissions. [6]

Continuous production of charcoal is more preferable to emission control than batch production because emission composition and flow rate are relatively constant. Emissions from continuous charcoal kilns generally are controlled with afterburners. Cyclones, which commonly are used for product recovery, also reduce PM emissions from continuous kilns. Afterburning is estimated to reduce emissions of PM, CO, and VOC by at least 80 percent. Control of emissions from batch-type charcoal kilns is difficult because the process and, consequently, the emissions are cyclic. Throughout the cycle, both the emission composition and flow rate change. Batch kilns do not typically have emission control devices, but some may use afterburners. [6]

Since the beginning of an intensive use of fossil fuels the global greenhouse gas (GHG) emissions have grown to 49.5 Giga tons of carbon dioxide equivalents in the year 2010. [7] GHG emission regulations, programs and policies have taken place and are further expected in order to mitigate the climate change caused by the elevated GHG levels in the atmosphere. The most significant actions have taken place in the past two to three years. [8]

2.2. Charcoal production technologies

Traditionally, charcoal is mostly produced using the earth-mound kiln. Four to seven days are necessary for charcoal production using this earth mound kiln, and heat loss slower its efficiency rating.

The traditional production process in open pits or kilns, as carried out in rural areas which is inefficient. Weight efficiencies of 10-15% are not uncommon, i.e. 7-10kg of wood to produce one kg of charcoal. [9] Depending on the sustainability of the wood used to make charcoal, greenhouse gas emissions released into the atmosphere could be substantial on the global level.[9]

Instead of older method charcoal production, a so-called ‘retort technology’ have developed. Retort–kilns have a much higher efficiency rating of 35%–40% in comparison with earth-mound kilns; they also reduce air pollution by up to approximately 75%, as the smoke produced is partly burned off during the carbonization process [10]. Another benefit is that the operating time for the retort kiln is much shorter about 12 hrs and about 12 hrs for cooling. [7]

There are many type of charcoal production kilns and retort technology. Retort is the standard method of production for industrial charcoal in western countries, but due to high investment costs it is not viable for traditional charcoal makers and small scale charcoal makers.

Table: 1. Kiln types and their charcoal production efficiency

Kiln type	Efficiency range (%)
Earth-mound	9–30
Casamance	17–30
Earth-pit	12–30
Metal	20–38
Brick and orange	27–35
Drum	20–38
Retort	22–40

Source [28]

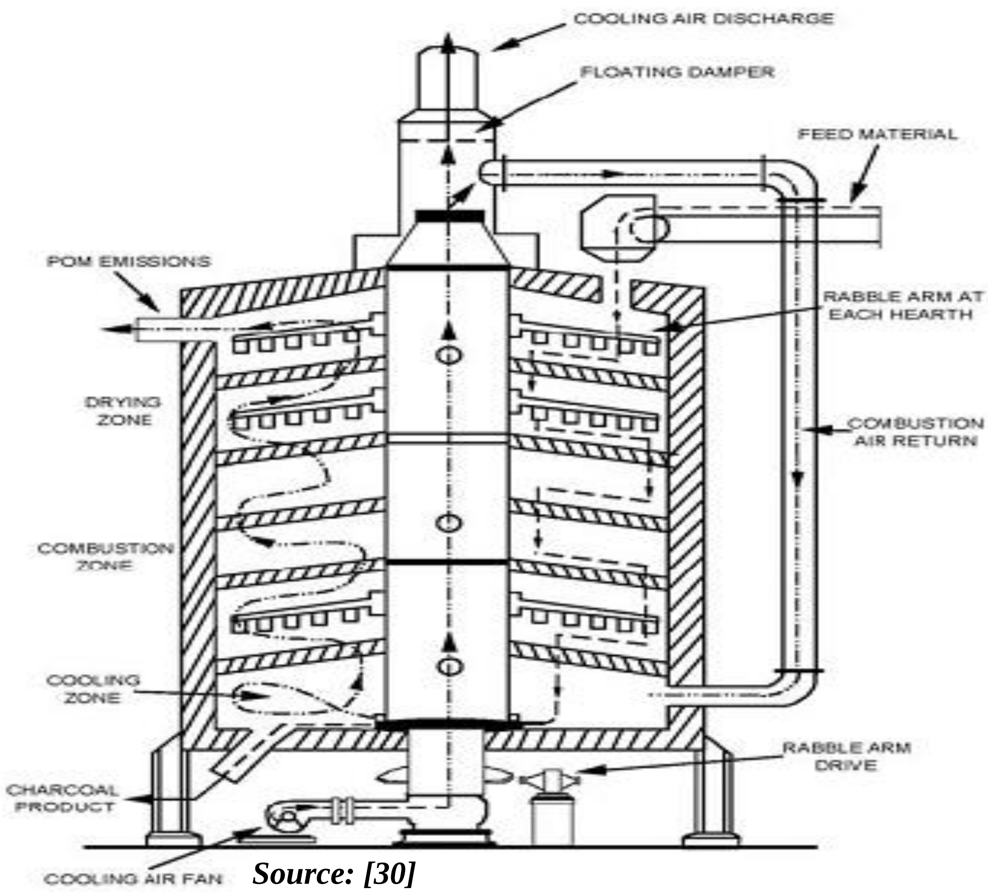
Now, a day more appropriate, efficient and affordable design has been developed to transfer and adapt this retort technology in rural or semi-industrial charcoal producer. Retort technology means that the charcoal is locked in a closed container where smoke and wood gases are only able to leave through one controlled opening. [5] The low cost retort kiln is called ICPS (Improved Charcoal Production System “Adam-retort’’). [10]

Adam retort built by two trained workers within a week. This retort turn over investment cost is about 5 months. The unit was developed in Burundi, East Africa and in India. This technology is simply to get high yield of charcoal at low cost production method and not has any emission mitigation techniques.

2.3. Retort Charcoal Production Technology

Most modern industrial charcoal makers use retorts for their process. In a retort, the pyrolysis vapors are separated from the feed material, before being combusted. Only the vapors are used to provide the energy sustaining the process. Exceptionally additional fuels are used, e.g. for start-up and in case of feed material that is too wet. Direct contact of the biomass feed with oxygen from air is being prevented. In this manner it ensured that the entire biomass feed is available for the conversion into charcoal. If carried out properly, charcoal yields from retort processes can be very high. However, the development of retort technologies in the past may have had other reasons than yield optimization alone: separation enables the manufacturer to produce a variety of chemicals, such as acetic acid, wood vinegar, and methanol. Today, the production of these by-products is no longer viable in view of the competition with other manufacturing processes.

There are many methods of implementing the retort principle. Most of them have been developed by the charcoal producers themselves, and few of them are commercially offered. An implication is that knowledge of the processes fades away, as firms who employ them halt their production over time. [10]



Source: [30]

Fig.1. A continuous multiple hearth kiln for charcoal production

Retort technologies are neglecting polluting gases, such as CH_4, CO and higher C-compounds. This is because the vapors are completely combusted into CO_2 and H_2O. [29] Also in terms of particulate emissions, the technology performs well, complying with the strict emission regulations. The avoidance of GHG emissions may be a relevant issue, if the technology is replacing traditional kilning technology, in view of obtaining project finance, which need millions of investment cost. [29]

2.4. Bricks

Clay bricks are major inputs in the building industry. They are mainly used to construct outside and inside (partition) walls of small and large buildings. Brick products are also used for roof tiles. Common wall bricks have standard dimension of 25x12x6.5cm. [33] Most wall bricks are solid, but there are also hollow bricks with different dimensions. Hollow bricks are relatively light and have good insulating properties. In general buildings made of clay bricks are cool in summer and warm in winter. Compared to building materials such as hollow blocks asbestos, and other synthetic wall making products, clay bricks have long durability. So durability of bricks also used for charcoal production kiln for its long life and heat managing property. For this research purpose [25x12x6] cm burnt bricks are selected which is collected from Ethio-Bricks Factory

2.5. Carbonization

Carbonization is process of charcoal production from biomass by pyrolysis method. There are many concepts and methods to produce charcoal. [16] The three types of carbonizing are:

- Internal heating: wood is directly ignited and pyrolysis under controlled air flow.
- External heating: this means another wood or combustible materials are heating the retort externally. The ignition of fire is contact direct the wood needed to be charcoal, but it take place by heat only.
- Heating with recirculated gas. Here wood is combusted first and the gas released is recirculate to heat another wood to be carbonized**.**

Combustion process depend on particle sizes which affect time of pyrolysis that the small size will combust first followed by higher size. Slow heating favor the formation of charcoal by enhancing the contact time of the volatiles with the solid carbon product. Volatiles are not stable at elevated temperatures in the presence of charcoal, or decomposing solid biomass. They adsorb onto the surface of the solid and quickly carbonize to releasing water, carbon dioxide, methane and another hydrocarbon as by-products. Fundamental research has also shown that there is a correlation between charcoal yield and lignin content of the feedstock, that is, higher lignin content gives higher charcoal yield. Between 30 and 60% of the energy content of the feedstock will be accumulated in the charcoal after carbonization. Charcoal production emit GHG and PM to environment, if not controlled. The yield of the different reaction products varies with biomass species and heating conditions.

2.6. Eucalyptus Tree for Charcoal production

Interest in renewable, CO_2 neutral, and sulfur-free biomass as a clean source of fuel, chemicals and materials is accelerating. [17] Many products currently derived from petrochemicals can be produced from biomass feed stocks: lubricants, polymers, high matrix composites, textiles, biodegradable plastics, paints, adhesives, thickeners, stabilizers and a range of cellulosic. [18] Biomass can be converted into a variety of energy products and chemicals [19] and for the production of iron alloys, particularly in Brazil and Australia.

Eucalyptus is the most valuable and widely planted hardwood in the world.[20] Eucalypts are grown extensively as exotic plantation species in tropical and subtropical regions throughout Africa, South America, Asia, and Australia, and, in more temperate regions of Europe, South America, North America, and Australia. Out of 12.751 million ha of eucalypt plantations reported to FAO in 2005, the almost 12 million are classified as productive forest. [21] A few eucalypt species and hybrids constitute the majority of these plantations. Fourspecies and their hybrids from this subgenus, Eucalyptus grandis(EG), E. urophylla(EU), E. camaldulensis, and E. globulus, account for about 80% of the eucalypt plantations worldwide.[21] Eucalyptus globulus is very important as fuelwood and for charcoal making, and it is an important source of pulp for the production of printing, writing, especially for production of tissue papers. [22] The Eucalyptus globulus is introduced to Ethiopia for its major role in the development of the country. Today the tree is important in and around Addis Ababa for its use as fuelwood and construction material and this plant cover 506,000 ha of land in Ethiopia. [12]

Brazil is the most charcoal producer on this world and 10% of the wood is harvested from eucalyptus trees clones which is estimated is 17,000,000 cubic meter per year in volume. [13] At the moment Ethiopia holds the largest population of eucalyptus tree in East Africa and is one of the first countries that introduced the species from European countries. Today the most important commercial eucalyptus species in this country are Eucalyptus globulus known locally as "Nech-Baharzaf" or "White Eucalypt" and Eucalyptus camaldulensis known locally as "Key-Baharzaf" or "Red Eucalypt". [15]

Eucalyptus globulus is selected to conduct this study. This plant is chosen because of its great climatic adaptability to high, cool elevations in tropical areas which include Ethiopian geological latitude. In Ethiopia and Portugal, at age 10 on the highest quality site, very good growth is 20 m^3/ha per year. [14]

2.7. Emission control method for PM and GHG

A wet scrubber is an air pollution control device that removes PM and acid gases from waste gas streams of stationary point sources. The pollutants are removed primarily through the impaction, diffusion, interception and/or absorption of the pollutant onto droplets of liquid. The liquid containing the pollutant is then collected for disposal. There are numerous types of wet scrubbers which remove both acid gas and PM. This chapter addresses the design and cost of wet scrubbers for control of PM_{10} and $PM_{2.5}$

Collection efficiencies for wet scrubbers vary with the particle size distribution of the waste gas stream. In general, collection efficiency decreases as the PM size decreases. Collection efficiencies also vary with scrubber type. Collection efficiencies range from greater than 99% for venture scrubbers to 40-60% (or lower) for simple spray towers. [25]

2.8. Gravel

Gravel is a pieces of stone composed of unconsolidated rock fragments that have a general particle size range and include size classes from granule- to boulder-sized fragments. Gravel is categorized by the Udden-Wentworth scale into granular gravel (2 to 4 mm) and pebble gravel (4 to 64 mm). The gravel selected for this project is pebble gravel is selected because of its property of washables to recycle and its inert nature. Gravel uses as a supportive media to increase contact of smoke and water/solutions. For maximum efficiency, gravel must possess the necessary attributes of hardness and be rounded rather than angular.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area

This study conducted at Oromia Region, West Shoa, Mida Kegn Wereda, Balemi Kebele. The area is located at 220km of west Addis Ababa.

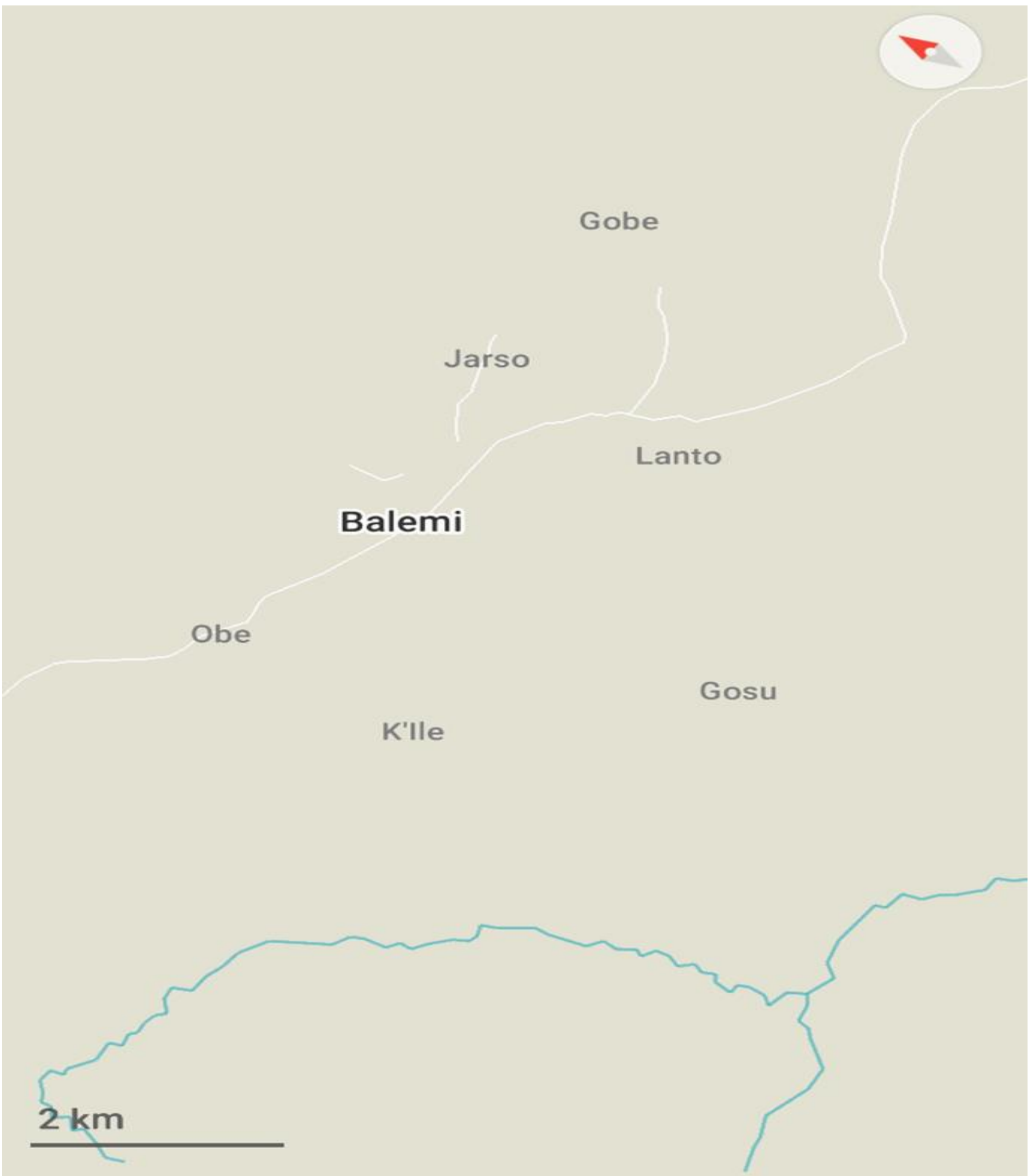


Fig: 2. Town of the Wereda and around Kebeles

The altitude of Balemi is around 2000m above sea level. It bounded by Calliya wereda on south, Jimma Rare on west, Tokke Kutaye and Ambo Wereda by east and Gindeberet by north. The weather of Balemi is like many highland part of Ethiopia, which earn around six month's rainy season. The around 90% of society source of income is agriculture. Key teff, bean, sorghum, wheat, flex, etc. are cereal cultivated in this wereda. Charcoal is also source of income for some part of society. In this wereda charcoal is produced from native trees.

The location of this study area has high tendency to plant eucalyptus tree because of high availability of over ground and underground water. This location is selected because of its appropriate area to get accesses required for the project and to get nearly traditional charcoal producers to get consult.

3.2. Materials

3.2.1. Burnt Clay Bricks

Brick is selected for building charcoal production kiln for its long life and heat resistance property. For this research purpose [25x12x6] cm burnt bricks have used, which was collected from Ethio-Bricks Factory.

Fig:3. Brick from Ethio bricks

3.2.2. Gravels

The gravel used for this project is pebble river gravel with aggregate size of 16mm to 20mm, 27mm to 33mm and 48mm to 60mm which is configured at the top, meddle and bottom respectively. Gravel selected because of its property of washables to recycle and its inert nature. Gravel uses as a supportive media to increase contact of smoke and water/solutions. For maximum efficiency.

Fig: 4: gravel type with 16-20mm, 27-33mm and 48-60mm size collected from river.

3.2.3. Wood

Wood type selected for this project is *Eucalyptus globulus*. This species highly planting on the highland of Ethiopia and the land covered by this plant is estimated as 506,000 ha before 15 years and it is doubled/tripled at this time. [12] In Africa over 90 % of the wood taken from forests is wood fuel. [39] Therefore, to protect the depletion of natural grown trees which are regenerate or not, using eucalyptus trees for charcoal production is the preferable. The study area is found on highland that *E.globulus* locally available. It cut and dried for four months and its moisture content reduced to 29.5%.

3.2.4. Another Auxiliary material

Another auxiliaries used in this project are:

- Cement to bind bricks
- Metal sheet to construct chimney, water tanker, wet packed scrubber tower and openings of kiln
- Water to absorb pollutant and wash trapped PM and other HC from gravel

3.2.5. Equipment used

- Gas Detector: detect gases like CO, CO_2, NOx and SOx
- Gas analyzer: analyze CO, CO_2 and HC

3.3. Methods

This project was performed by constructing kiln and emission controlling method.

3.3.1. Kiln design

Brick kilns are used for batch charcoal production process and it can built with various shapes; such as beehive kiln (Brazil), half orange kiln (Argentina), rectangular kiln (Adam retort), Missouri kiln and others. Kilns are built with different dimensions and designs for the required capacities. For example, small-sized kilns producing 4-5 bags to those that can produce 80-120 bags. Different researchers stated that the kiln walls are 30 - 40cm thick for small sized kilns and 42- 48cm thick for larger kilns to insulate the wood carbonizing from excessive heat loss. [23]

For this research the bases to select the dimensions of kiln was, the volume of wood wanted to test for single batch and 20% of the kiln volume was left for space above the wood. The other consideration was that rectangular kiln was selected because of its simplicity and Adam rectangular shape high efficiency. Therefore kiln dimensions were 156cmx116cmx146cm (while internal dimensions 120x80x130cm). The following steps were used to construct kiln:

- The ground was levelled for kiln construction
- It built with air inlets at the base while hole/chimney which control outflow of gases was placed at top of one end side
- Kiln built as a pilot test with internal dimension of 0.8mx1.2mx1.3m (WxLxH) which give as 1.25m^3 volume which kiln construction took two days to build and 500 pieces of bricks by two trained workers and two labors
- This kiln have one opening on top for wood charging and closed after wood is ignited. Also there is small door made of metal sheet on front wall of the kiln for charcoal discharge

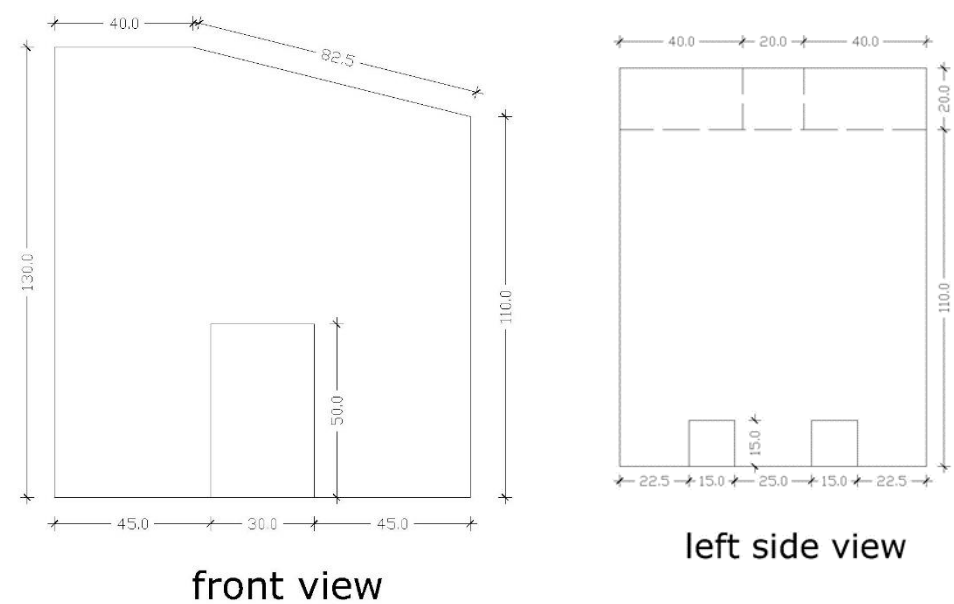


Fig: 5. Kiln design (front and left side view)

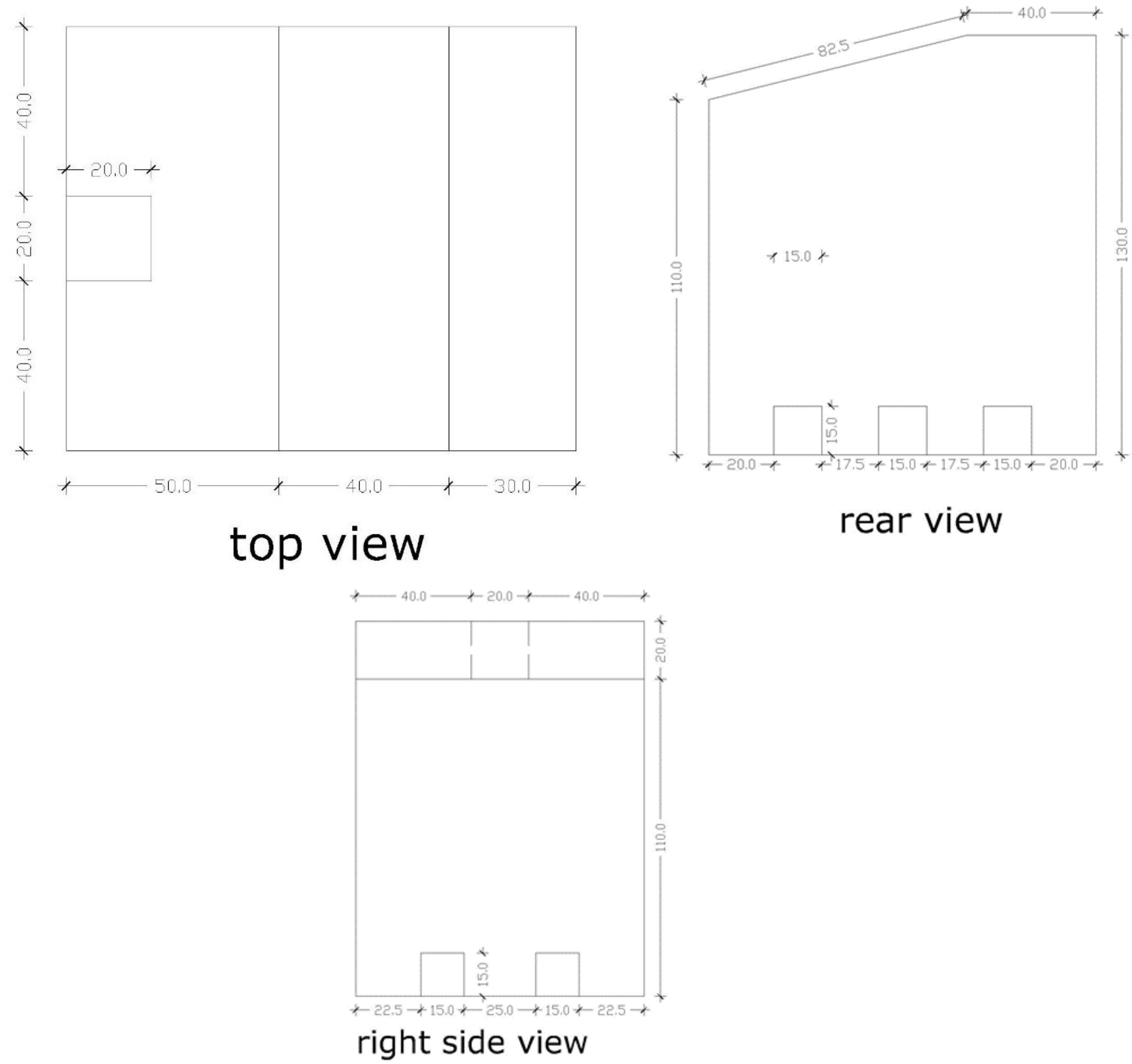


Fig: 6. kiln design views

3.3.2. Wet Packed Scrubber Design

Wet packed scrubbers are the most appropriate air pollution control device for collecting both particulate matters and gas in a single system. Particulate matters trapped on gravel and water droplet absorb gases like CO and CO2 from smoke, while gravel washed by flew down stream. Emission enter the bottom of the tower and this polluted airstream flows upward through a wetted packing which is chemically inactive packing (gravel) material. The liquid absorbent flows downward and is uniformly spread throughout the column packing, thereby increasing the total area of contact between gas and liquid. Most of this systems are cylindrical, while this design is rectangular, because of the difficulty of cylindrical construction.

The design of this device developed from different assumptions and data collected from amount of emission from the kiln designed above. From the designed kiln 89.8kg of solid was collected from 223kg of wood which shown 133.2kg of weight was emitted to atmosphere. This process took 16hours to complete. Therefore mass flow rate (m_f) calculated was 133.2kg/16hrs which gives 8.325kg/hr. The other parameters used to calculate the dimensions of the tower is effective density of the smoke emitting from the kiln at the combustion/carbonization phase. Therefore at steady combustion phase produced agglomerates with effective density of roughly 1 g/cm^3 for small particles. [40]

From ideal gas law,

$$PV = nRT$$

Can be solved for the gas volume to get: $V = \frac{nRT}{P}$.............................(1)

Gas density is defined as: $\rho = m/V$...(2)

Substituting equation (1) into equation (2) redefines gas density as: $\rho = \frac{mP}{nRT}$......(3)

Therefore, mass flow is equal to density times volumetric flow rate: $m_f = \rho.\ V_f$ ....(4)

From equation (4), V_f calculated as: $V_f = m_f/\ \rho$ [41]

Then $V_f = 8.325\text{x}10^{-3}\ m^3/hr$

Assuming the depth of the tower 0.4m (because flow of emission in higher depth has higher collection efficiency which increase residential time of particles than immediate pass through the packing) and square area of the tower assumed (because to facilitate uniform dispersion of airstream in tower), the dimensions of the tower calculated which gave 15x15x40cm (LxWxH).

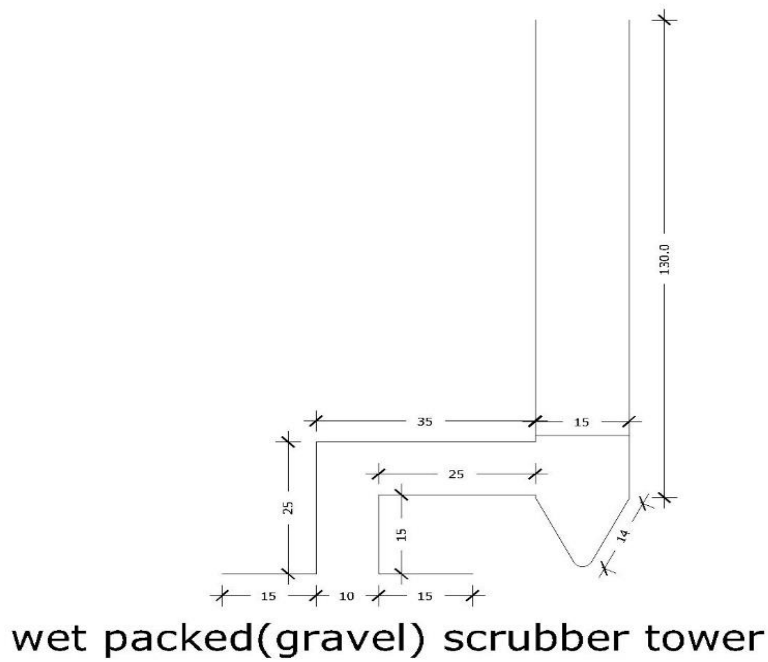


Fig: 7. Design of wet packed scrubber

This emission control device were constructed using available materials, which helps small scale and commercial charcoal producers to control emission at low cost. Wet packed scrubber built from metal sheet with 15cmX15cmX1.30m over all dimension. The base of the tower is covered with hollow metal sheet which allow flow of gas up and liquid down by holding gravels in the tower and it is connected to chimney below 0.3m of its total height. From 1.30m depth 0.4m was filled with gravel and 60cm depth above gravel left empty which use to control dispersed water. Chimney connect the kiln with wet packed scrubber to transport smoke and water storing tank was installed above the tower to shower water by gravity

3.3.3. Wood preparation

Wood was harvested before 4 months have around 10 year old *eucalyptus globulus* and cleaved to decrease size and kept under shelter to protect the wet contact which affect the carbonization process by value of water in the wood. For this test wood had average moisture content 29.5% and 223kg weight. To make good carbonization, wood was prepared with length of (80 -100) cm and diameters of (14-30) cm wood are charged to the kiln in well-arranged form to initiate initial ignition of wood.

3.3.4. Carbonization

Carbonization is the term for the Carbonization means drying wood below 0% moisture content which means heating at 100^{o}C and it is conversion of an organic substance into carbon or a carbon-containing (charcoal) residue through pyrolysis. There are many steps followed to carbonize wood into charcoal. For this pilot project internal heating is selected because of its simplicity and conserve wood extravagated for retort heating. Also internal heating is chosen over heating with recirculating gas, that this need high investment cost and skilled producer to use heat another process for next process.

- ✓ The cleaved wood stacked upright and the wood piled horizontally on the top layer of the upright wood. Here base hole are kept free/not blocked for ignition and air inflow at the beginning of carbonization.

Fig: 8. Loaded wood in kiln

- ✓ wood fired through base holes
- ✓ The upper opening closed after 10 -15 minute wood of lighting
- ✓ Bricks put on upper door and smeared with slurry made from mixture of mud and ash to protect heat and volatile material leakage.

- ✓ Wood carbonize allowed until bluish smoke is emitted from the chimney.
- ✓ Air inlets (holes) blocked with bricks and mixture of mud and ash. Then carbonizing was continued for 16 hrs (lighted @ 2:14 pm and continued carbonizing during the night and on next day @ 6:20 am) and chimney also closed and allowed to cool.
- ✓ Kiln side door opened and charcoal was discharged after it cooled. Soil was required to protect the re-ignition charcoal when exposed to air.

Fig: 9. Carbonization steps and smoke color difference

Generally, products and byproducts from charcoal production operations are: charcoal, gases like carbon monoxide (CO_2), carbon dioxide (CO), methane, ethane, particulate matters, tars and heavy oils, and water. With the exception of charcoal, all of these materials are emitted with the kiln exhaust.

3.3.5. Emissions and Control Method

Wet packed (gravel) scrubber designed from gravel packing for its high collection efficiency and for maximum corrosion resistance. Gravels arranged with different size and configuration that gravel with 48-60mm aggregate size configured at the bottom of the tower (which enhance the smoke flow in the gravel with slight challenge), gravel with 27-33mm aggregate size filled the middle part of the tower to narrowing the space between gravels and gravel with 16-20mm aggregate size at the top of the two layers. This configuration was shuffled to get the best result.

Fig: 10. Gravel arrangement from top to bottom

Therefore, using the above setup, test conducted three times:

1. The first was conducted by fixing the bottom part (48-60mm) with 20cm thickness, middle part (27-33mm) with 10cm thickness and top (16-20mm) with 10cm thickness. Therefore, outgassing flew from chimney into the tower. Then it contact with the higher size gravel which not block flow of gases fully, but it is not straight forward to pass. The

flow of gases continue in the middle and top parts which increase challenge on flow of gases toward the top.

2. The second test was conducted by removing the higher size (48-60mm) from the bottom fully and arranging the two sizes (27-33mm and 16-20mm) by equal (20cm) thickness.
3. The third was tested by remove the two type (27-33mm and 16-20mm) and the total height (40cm) filled with higher size (48-60mm) gravels. (The result shown in table 2)

In these process emission loss their speed and PM are trapped on the gravels while water/solution is showered downward by shower head to clean every gravels and absorb material from gases stream. Therefore this condition remove pollutants from emitted gases and at last, clean/treated gases flew out to atmosphere.

3.3.6. Economical Analysis

As stated above there are many materials used to realize the project. The following tables shows the list of material and labor cost.

Table:2. Raw material cost

Raw material	Unit	Amount	Unit price	Total (in birr)
Bricks	Pieces	500	5 birr	2500
Metal sheet		3	260	720
Cement	Kg	300	2.60	780
Sand	m^3	3	260	780
Wood	m^3	1.1	233	256
Total				**5,036**

Table: 3. Labor cost

Duties	Number of person	Cost per person (in birr)	Total cost (in birr)
For kiln construction	2 for two days	150	600
For Gravel collection	2 for one day	50	100
For wet packed scrubber construction	2 for two days	200	800
Total			**1,500**

The cost was transportation cost to transport bricks from Burayu to Mida kegn which 800 ETB Therefore the total initial cost of this project was **7,336 ETB**.

This kiln can produce 15 batch per month which give 39bags. While labor cost for charcoal production is 1400ETB for two workers. The other cost is 600 ETB to transport 40bags of charcoal to the market. The price of one bag is 180ETB and it will be 7,200ETB per month. The total variable cost is wood cost which will give 3,840ETB. Therefore, production cost per bag is 146ETB. The net profit of this project is 1,360ETB per month, which help to payback the initial investment cost in six month.

3.4. Result and Discussion

3.4.1. Kiln Characterization

Rectangular brick kiln is built with 1.25m^3 volume and 18cm wall thickness. This thickness not satisfy kiln required standard thickness that the kiln had to build from double bricks rather than from single brick for good carbonization. Most researchers used 30cm to 40cm for small scale production and 40cm to 50cm for commercial scale production of charcoal. [23] Thin wall loss heat that affect efficiency of kiln. As result it reduce charcoal yield and increase CO_2 emission because of sufficient air leaking in to the kiln. This kiln conversion capacity at stated condition was 38% and the efficient kiln is Adam retort which has 30-40% conversion rate. [5] it may be because of kiln wall was constructed from double brick.

This kiln still more efficient than traditional earth kiln (15-20%), cassamance kiln (26-30%), drum kiln (20-30%), portable metal kiln (26-30). [27], [29] At low cost, this kiln preferable for those produce charcoal with low efficient kilns listed above and others.

3.4.2. Charcoal Characteristics

The carbonization process took 16 hrs and a day for cooling. From this process 85kg of charcoal is collected which is 2.6 bags with weight of 31.6 kg per bag. This weight consider only the core charcoal which have more than 20mm aggregate size. There is 3.5kg less than 20mm aggregate size (fine) charcoal and the ash was 1.8kg. This shows *eucalyptus globulus* is good firewood for charcoal production. The moisture content of this charcoal is 9% which the interval of standard charcoal moisture is (5-15%). Ash content of the produced charcoal was 1.5% which shows moderately good charcoal, that the lower ash content charcoal gives high heating value. Charcoal yield obtained from the *Eucalyptus globulus* is considered satisfactory and it could be replace non regenerating plants for charcoal production.

3.4.3. Emission and Wet Packed Scrubber Characterization

All of us think that charcoal is the cheapest energy source, that produce from biomass and it available and affordable. Biomass energies can be said “green energy”, because of mass balance between plants and their product is zero. What they give off when combusted is what they took from atmosphere and ground when they grew. However, charcoal production need emission control technology, because of the environment is already polluted. For this purpose, emission control method is developed in this research using wet packed scrubber which treat gases, water vapor, PM and heavy oil produced from carbonization unit. When pollutant like water vapor, PM and heavy oils are obligated to pass through wet packed scrubber they are expected to left on gravel and washed by water shower, while gases absorbed by water droplets.

Before applying the treatment using wet packed scrubber it was needed to measure content and concentration of emission as shown in table 1.

Table: 4. Results of emission measured at exhaust

HC	CO	CO_2	O_2	Time
1959 ppm	5.6%	18.91%	0.00%	03:02:21 pm

The gases content and concentration measured, when smoke changed to bluish because of the dark/black smokes emit during carbonization star not determine the concentration of gases to analysis. Another reason was dark/black smoke emitted for short time that the kiln was closed after wood was ignited which took around 15-30 minute. This time was not enough to measure gases content and concentration.

Table: 5. Results collected after emission control

No	gravel size	Thicknes s	HC in ppm	CO in (%)	CO_2 in (%)	O_2 in (%)	Time of test On the same day
First test	48-60mm bottom 27-33mm middle 16-20mm top	20cm, 10cm, 10cm	59	0.31	2.12	0.00	03:30:12 pm
Second Test	27-33mm bottom 16-20mm top	20cm 20cm	43	0.04	0.28	0.00	03:40:51 pm
Third test	48-60mm full	40cm	263	1.80	11.93	0.00	03:45:59 pm

Table 4, shows before treatment, combustion emissions originate in smoke are gases like CO_2 and CO and HC which was measured by “Gas Analyzer”. Hydrocarbon measured in ppm (1959ppm) while CO and CO_2 were measured in percent of their concentration in the emission.

The trapped particulate matter on gravel washed with down flew water while it absorb GHG and another acid gases, if they exist.

Using gas detector CO_2 = 65,593ppm and CO = 1546ppm. Gas detector can detect gases like NOx, SOx, and Cox. But test taken from this experiment shows absence of NOx and SOx. Therefore, charcoal production from eucalyptus trees and another plant is free of nitrogen oxides and sulfur oxides. These gases may found charcoal production from solid waste, because of some chemicals may mixed in solid wastes.

The first test shows that CO is cleared by 94.5% and 1460.42ppm, CO_2 reduced 88.8% and 58,246.6ppm from 65,593ppm and HC reduced by 97% and 1900ppm from 1959ppm.

The second test gave that CO was 5.6% before treated and 0.04% after treated. This means 99% of CO was absorbed from emission and 1535ppm absorbed out of 1546ppm. CO_2 reduced by 98.5% and 64,622ppm out of 65,593ppm and HC decreased 97.8% which means 1916ppm absorbed from 1959ppm.

From third test CO treated by 67.85% and 1,049ppm from 1546ppm, CO_2 absorbed by 36.9% and 24,211ppm from 65,593ppm and HC reduced by 86.6% and 1,696% from 1959ppm.

As shown in the above data, the best result achieved from the second test which gravels were arranged 27mm-33mm set at the bottom with 20cm thickness and the size 16mm-20mm gravels fixed at the top with 20cm thickness.

Fig:11. The required two layers for

The two layer help the contact of water and gases by decreasing their speed. When water contact with gases like CO and CO_2, it gives carbonic acid which is a weak acid and dissociates to carbonic ions that ready to react with Ca, Mg, CaO and another elements and ions. By being economical, lime may be used to neutralize acidity of the waste water.

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H^0{}_{298} = -41.09\ \text{kJ/mol}$$

$$CO_2\,(aq) + H_2O(l) \leftrightarrow H_2CO_3\,(aq)$$ [32]

From one tone wood carbonized, 365kg is released to environment. [31] which means 365kg x 0.056 of CO which gives 20kg and this technology reduce CO by 19.8kg while CO_2 reduced by 67.9kg out of 69kg.

Therefore, this technology is more efficient with layers of gravel composed lower size and it is versatile control technology comparing with fabric filter which filter only PM, wet scrubber which not efficient/need high cost and cyclone which work only for PM. Additional advantage of this technology is the packing gravel is recyclable after a batch or many batch of production. The drawback of this technology is that the packing material is stone which is heavy that need strong holding above the kiln.

3.5. Conclusions and recommendations

3.5.1. Conclusions

The kiln built for this pilot project can be called as improved brick kiln (IBK), because of the kiln was built from single brick which minimize building cost as well as its conversion efficiency was moderately high (38%). Charcoal produced from *eucalyptus globulus* also had shown good properties such as moisture content in range good charcoal and ash content which is low for good energy generation. One batch charcoal production took 36hrs that carbonization took 12hrs and a day required for cooling. This shows that the kiln achieve the short time of carbonization. So that the IBK can solve the problem of charcoal producer at small scale at low cost.

Charcoal production emits GHG, PM and HC to environment and it could controlled perfectly by designed wet packed (gravel) scrubber. Its efficiency was 99% for CO, 98.5% for CO_2 and 97.8% HC. The result got from this test shows that the technology have good solution for environmental protection plan.

From the second test wet packed (gravel) scrubber using the lower size gravel packing emission had reduced as: CO and CO_2 by 19.8kg out of 20kg and 67.9kg from 69kg from 1000kg of wood carbonized. The second test were efficient by 4.5% than the first for CO, 10% for CO_2 and more efficient than the third test. Therefore gravel packing the given tower by lower size give the best efficiency. On other hand this technology can built initially by low cost (7,080ETB), which can paid back in six months.

Hence this technology was feasible, simple to construct and adaptable. Therefore, appropriate to control emission from charcoal production at small scale.

3.5.2. Recommendations

- The heating value of charcoal not measured for this project because of absence of functional bomb calorimeter equipment. But it should be measured that it is one parameter to characterize charcoal.
- Research are required to optimize the technology by considering factors like flow rate of gases and water, concentration of gases, volume of wet packed scrubber tower and depth of gravel and size of gravel.
- The feasibility of wet packed (gravel) scrubber should be studied to scale up the technology.
- After the technology is optimized it will be efficient to control greenhouse gases and particulate matters.
- For Ethiopia charcoal production will free of environmental imbalance by producing charcoal from *eucalyptus globulus* tree which is highly planted and planting over all highland regions the country.

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Appendixes

Kiln construction steps

Print out result from gas analyzer